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A Comprehensive Review on Blast Furnace

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Abstract: **The design and control of blast furnace (BF) ironmaking must be optimized in order to be competitive and sustainable, particularly under the more and more demanding and tough economic and environmental conditions. To achieve this, it is necessary to understand the complex multiphase flow, heat and mass transfer, and global performance of a BF. In this paper injection of alternative reducing agents via lances in the tubers of blast furnaces is discussed to reduce the consumption of metallurgical coke. Besides liquid hydrocarbons and pulverized coal the injection of recycled waste plastics is possible, offering the opportunity to chemically reuse waste material and also utilize the energy contained in such remnants.**

KEYWORDS: Stave cooler, Blast Furnace cooling, Lining cooling.

I. INTRODUCTION

Blast furnace (BF) ironmaking is the most important technology by which hot metal is rapidly and efficiently reduced from ferrous materials. In an integrated steelwork, BFs together with the associated units represent about 90% of the CO2 emission [1] and 70% of the energy consumption [2]. Therefore, it is important to minimize the rate of reducing agent and to make full use of energy in the BF ironmaking process. Essentially, this requires that the heat exchange and chemical reactions between different phases proceed properly in every region of a BF. In pursuit of such a goal, extensive experimental and numerical efforts have been made in the past to study the in-furnace multiphase flow, heat and mass transfer, and global performance of BFs, toward achieving reliable, cost- and energy-effective, and low-emission production ultimately [3].

The majority of liquid raw iron is produced via the blast furnace route, traditionally utilizing metallurgical coke as the main reducing agent. Aiming at a reduction of primary resources, using alternative reducing agents such as liquid hydrocarbons, natural gas and waste plastics contributes to the reduction of coke rates [4]. In the blast furnace these agents also deliver the heat necessary for melting processes as well as endothermic reduction reactions. To optimize the utilization of the input materials, thorough examination of the impact of fuel injection is necessary. However, due to the extreme conditions in the blast furnace, the application of experimental techniques is very limited [5]. A promising alternative is to conduct numerical experiments applying the methods of computational fluid dynamics. The modeling capabilities of the solver were extended to include the description of multiple phases such as injection of reducing agents, Homogeneous reactions, heterogeneous reaction, etc.

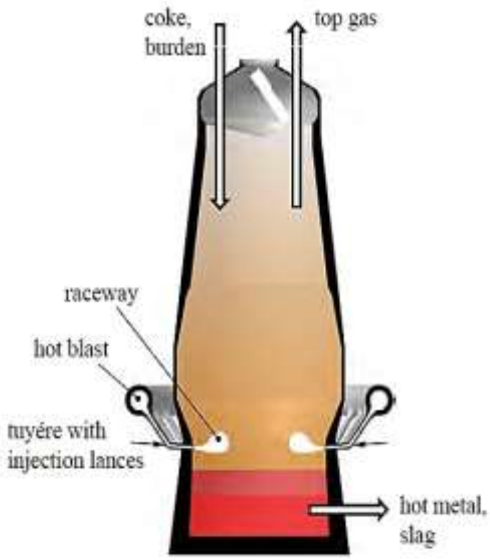

Figure 1: Blast furnace scheme

A. Injection of alternative reducing agents

The injection of liquid hydrocarbons and plastic particles is modeled applying tracking schemes in a Lagrangian frame of reference. Heating rates are computed accounting for contributions from laminar and turbulent convective transfer as well as radiation. The release of mass from the liquid fuel to the gas phase is computed applying a multicomponent evaporation model based on temperature dependent saturation pressures of mixture components.

B. Homogeneous reactions

Rates of homogeneous gas-phase reactions are calculated considering reactant mixing on finest scales of turbulent eddies in a set of global reactions. The considered reactions are:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \quad \text{(i)}$$

$$2CO + O_2 \longleftrightarrow 2CO_2 \quad \text{(ii)}$$

$$2H_2 + O_2 \longrightarrow 2H_2O \quad \text{(iii)}$$

$$CO + H_2O \longleftrightarrow CO_2 + H_2 \quad \text{(iv)}$$

$$CH_4 \longleftrightarrow Cs + 2H_2 \quad \text{(v)}$$

Cracking of hydrocarbon vapor to form smaller gaseous constituents as well as combustion is modeled in the gaseous regime:

$$C_{19}H_{30} + 17O_2 \longrightarrow 19CO + 15H_2O \quad \text{(vi)}$$

$$C_{19}H_{30} + 6O_2 \longrightarrow H_2 + 7CH_4 + 12CO \quad \text{(vii)}$$

$$C_{19}H_{30} \longrightarrow Cs + 3H_2 + 6CH_4 \quad \text{(viii)}$$

C. Heterogeneous reactions

Heterogeneous reactions of coke with gas mixture components are evaluated considering major reaction routes such as oxidation, steam and CO2 gasification and methanation:

$$CH_xO_y(s) + (x_4 - y_2)O_2 kO_2 \rightarrow CO_2 + x\ 2H_2O \quad \text{(ix)}$$

$$CH_xO_y(s) + CO_2 kCO_2 \rightarrow 2CO + yH_2 + (x_2 - y)H_2O \quad \text{(x)}$$

$$CH_xO_y(s) + (1-y)H2O\ kH2O \rightarrow CO + (1 + x_2 - y)H_2 \quad \text{(xi)}$$

$$CH_xO_y(s) + (2 + y - x_2)H_2\ kH_2 \rightarrow CH_4 + yH_2O \quad \text{(xii)}$$

The thickness of the particle boundary layer strongly depends on local gas flow conditions, particle properties and coke bed and is calculated with respect to local turbulence and gas phase properties. The diffusive transport processes are considered as a series of resistances to the actual chemical reaction. This approach allows for the computation of effective reaction kinetics for wide temperature ranges.

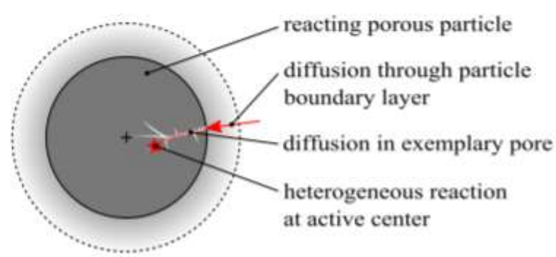

Figure 2: Schematic illustration of educts species diffusion from gas bulk flow towards the actual reaction site

The heats of reactions are computed from standard state enthalpy differences at local temperatures using polynomial expressions available for thermo physical properties. The standard enthalpy of formation of solid coke was estimated from the tabulated values of gas species involved in the combustion reaction using the lower heat of combustion of coke given from experimental examination.

II. LITERATURE REVIEW

Shan-Wen Du [1] solved the Navier–Stokes equation, the thermal-energy-balance equation with conjugated heat transfer, and the mass transfer equation at steady state to predicts the decrease in temperature of the eroded hearth of the blast furnace.

Chen ching-wen [2] Modified single lance injection into double lance injection for pulverized coal injection (PCI) system they developed a three-dimensional mathematical model on computational fluid dynamics software

PHOENICS to simulate the fluid flow phenomena inside blast furnace tuyere.

D. Maldonad [3] validated three-dimensional numerical model of the blowpipe/tuyere/raceway for various plant-specific investigations of blast parameters such as oxygen enrichment, blast temperature and atomic oxygen-to-carbon ratio. The methodology combines 3-D CFD model, which is used to predict the hot face temperature for a given inner profile, 1-D heat transfer model, which is used to predict fine tune the inner profile. The conclusion was made that many of the research is already done in hearth portion. From this, the conclusion is made to study some other part of the blast furnace except hearth, then after getting deep into the blast furnace, a point was made that only a few researchers did study in the tuyere portion.

W.Lijun et al. [4] have analyzed three dimensional model stave of blast furnace using ANSYS. They found that reducing the temperature of water and increasing the velocity of water would be uneconomical. They controlled thermal stress and maximum temperature in the state by properly adjusting operating conditions of the blast furnace, operating conditions are the coating layer, gas flow, lining material and cooling channel inter-distance and gas clearance and Diameter.

W. Zhou et al. [5] have studied on the hot face of blast furnace stave cooler. They have used two equivalent convection coefficients between gas flow and inlaid brick, and gas flow and stave body. They found that equivalent convection coefficient increased the accuracy of heat transfer numerical calculation.

W. Lijun et al. [6] have studied on intelligent monitoring methodology based on the mathematical model of blast furnace stave and developed intelligent simulation technique this intelligent simulation model of cast steel stave cooler is based on correction factor of parameters obtained by training the samples of test data of the cast steel cooling stave. They found that the data of intelligent simulation model is nearly consistent with that of experiment.

K. Verscheure et al. [7] have adopted new technology for furnace cooling in pyrometallurgical Processes. furnace cooling is very important for blast furnace, which is a key of increasing related to the pyrometallurgical industry as it can fundamental increase productivity, process intensities, and campaign life of furnaces. They also imposed a variety of problems mainly related to sustainability of the operations, safety, heat losses and .They found different cooling designs used in the non-ferrous, ferrous and alloying industries and aspects of furnace monitoring, materials selection, manufacturing, water quality and installation when using water cooled refractory.

U. Pückoff and CH. Knoche [8] have employed various techniques cool the shell of the blast furnace bosh, belly and stack are .In earlier times, cooling boxes of varying design, number and size were used exclusively for the transferring of the waste heat of the furnace to a cooling medium ,mainly in conjunction with external cooling ,whereas during the 1970s, cast iron plate coolers, so-called staves, have attained worldwide importance for furnace cooling . The plates which have a considerable area and which are traversed by a cooling medium form an almost gap-free internal cooling of the furnace shell. Since the introduction of these staves, originally a Soviet discovery, there has been no shortage of development work, they adapted cast and cooling pipe materials, together with the overall plate construction and installation to the extreme conditions of stress in a modern large high-performance blast furnace.

III. BLAST FURNACE IRONMAKING

A blast furnace is a vertical counter-current heat exchange and chemical reactor for producing hot metal [9]. Solid iron oxide burden is charged from top along with coke and flux, and as it descends in the furnace it is heated up by the ascending gas and the iron oxides are reduced into hot metal by the reducing gas. Figure 3 shows the cross section of a typical blast furnace along with the inputs and outputs. The blast furnace parts may be classified depending on the shape of the region. The upper cylindrical part of the furnace is known as the throat and is protected by refractory brick. Below the throat, there is the region with increasing diameter known as the shaft which extends to a cylindrical section or belly. After the belly, the diameter decreases again in the bosh region, where the blast enters the furnace. The bottommost portion of the furnace is called the hearth where the molten hot metal and the slag accumulate within a coke bed [10]. The inner volume of the blast furnace is also classified into different zones (Figure 4) depending on the physical state of the burden and the chemical reactions occurring. The uppermost part of the furnace constitutes of the lumpy zone, where the burden remains solid. The iron ore, usually charged as hematite (Fe_2O_3) is first converted to magnetite (Fe_3O_4) and eventually to wustite1 (FeO) by the ascending reducing gas containing carbon monoxide (CO) which produces carbon dioxide (CO_2).

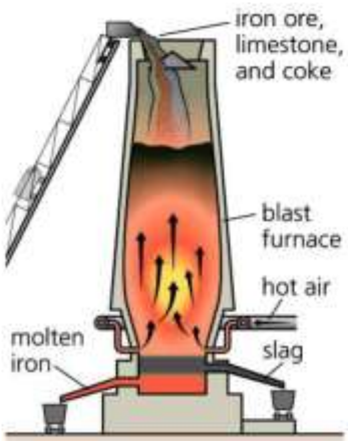

Figure 3: **Cross-section of a typical blast furnace, classification based on shape of the furnace region.**

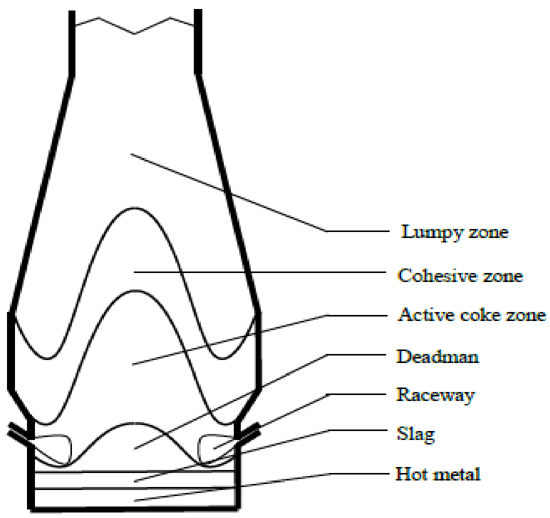

Figure 4: Different zones of the blast furnace classified on the basis of internal state.

A. Burden distribution

The blast furnace is a continuous reactor but the raw materials are charged in alternate layers of ore and coke intermittently. This layered structure is retained as the raw materials descend through the furnace. Burden distribution refers to this arrangement of the layers of different materials inside the furnace and mainly to the radial distribution (as axial symmetry is usually desired). The raw materials charged into the furnace are very different from each other. Ore is about four times heavier than coke and the particle size is 2-4 times smaller, which affects the gas permeability and heating of the charged layers. As the reducing gas rises from below, it encounters the burden layers with very different permeability conditions. The radial distribution of ore and coke is therefore an important factor governing the gas flow distribution in the furnace [8]. Normally, the fraction of ore of the total volume or mass is used to quantify this distribution. The (radial) region with higher fraction of ore results in a lower gas flow. In some operating procedures, higher gas flow at the center of the furnace is preferred, because it is effective in decreasing discontinuous motion of the solid burden, resulting in smooth operation [10].

B. **Charging equipment**

Once it has been charged into the furnace as the layers maintain their relative structure quite well until the cohesive zone commences. Burden distribution in blast furnaces is controlled by adjusting the parameters of the charging equipment. Each furnace is charged according to a list, known as 'charging program', which consists of the material name, amount and the corresponding set of parameters which determine how the material is to be charged into the furnace.

i. Bell top

A bell top charging system consists of a bell and hopper arrangement. The bell blocks the opening of the hopper when it is raised and when the bell is lowered the raw material falls into the furnace. The hot "top gases" are rich in energy and should therefore be recovered; so a single bell hopper system cannot be used.

ii. Bell-less top

Bell-less top charging systems are relatively new charging units which are becoming increasingly popular. This system was developed by Paul Wurth with its first successful industrial application in 1972. It consists of a gated hopper which empties into a chute which is rotating about the axis of symmetry. The inclination of the chute may be controlled and, therefore, provides much higher flexibility to the operator as to choose the size and position of the dump. This is one reason why bell-less charging is preferred over the bell top charging.

iii. Gimbal top

The Gimbal top is a comparatively new burden distribution system introduced in 2003 by Siemens VAI [11]. It utilizes a conical distribution chute with rings which allow multi-axis motion. This technology gives more flexibility to the furnace operator compared to the bell-less top charging system. The charge may be directed to any point on the furnace stock line. It allows sector charging, spot charging and formation of a true center coke charge. This charging system has been applied to a few FINEX and COREX furnaces along with the C Blast Furnace of Tata Steel in Jamshedpur.

iv. Bell-less rotary charging unit

A bell-less rotary charging system was developed by Totem Co. Ltd. [12]. It consists of a rotary chute, whose speed determines the positions at which the material is charged. It charges thin layers of the material, so the dump does not affect the burden surface on which the dump is charged (referred as 'soft dumping'). Some blast furnaces in India have been equipped with this charging system.

v. No-bell top charging system

The no-bell charging system consists of a double chute system with a rotating chute at a fixed angle with an additional chute at the end to direct the charge to a particular radial position on the burden surface.

C. Measurement technology for blast furnace burden distribution

Efficient blast furnace control requires reliable measurements of the conditions inside the furnace. The temperatures in the lower half of the furnace may increase to more than 2000˚C, where most intrusive measurement technologies would be unreliable, so most of the in furnace measurements are carried out above or near the burden surface.

IV. CONCLUSION

The efficiency of a blast furnace depends largely on the gas flow pattern inside it, as the gas phase is central in the reduction reactions and in the heat transfer. The bed in a blast furnace consists of layers of materials with different physical properties, including density, voidage, particle size and shape. Therefore, controlling the burden distribution is the primary method for achieving a proper gas flow in the furnace and practically the only means of directly controlling the radial distribution of variables in the process. Thus, it is crucial for the furnace operator to understand the effect of the charging program on the formation, shape and thickness of the burden layers. The study will be applied to further operating conditions including e.g. oxygen enrichment levels, hot blast temperature and hot metal production rates.

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